SCENE
(Scintillation Efficiency of Noble Elements)

Hugh Lippincott

Liquid Argon R&D Review

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Member Institutions:

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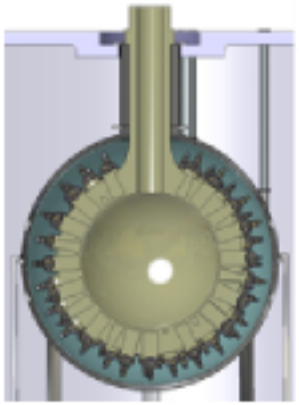
Liquid Argon (LAr) as WIMP Target

S1 or Scintillation: Excellent pulse shape discrimination (PSD) of nuclear (NR) versus electron recoils (ER)

Single-phase
S1 only

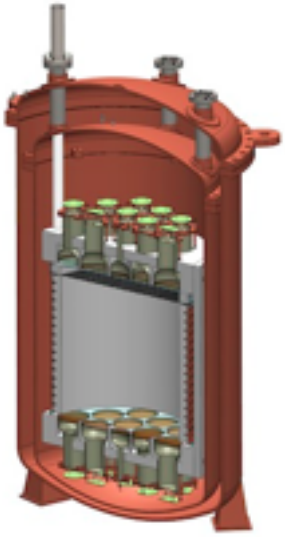


DEAP

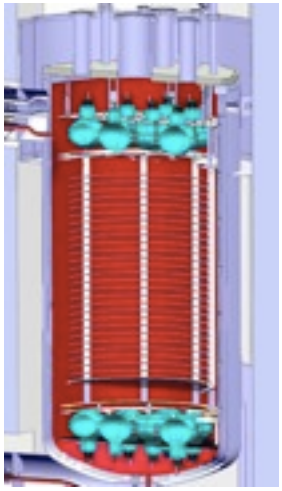
CLEAN

S2 or Ionization: enables position reconstruction and additional ER discrimination

Dual-phase
S1+S2



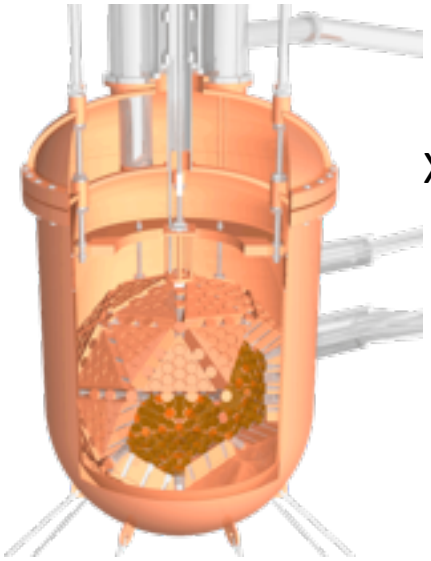
DarkSide



ArDM

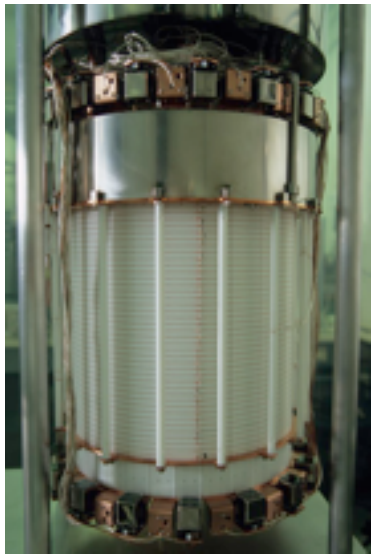
Liquid Xenon (LXe) as WIMP Target

Single-phase
S1 only



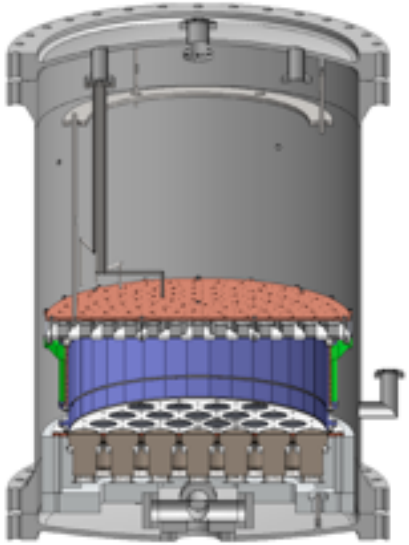
XMass

Dual-phase
S1+S2



Xenon100/1T

LUX/LZ



PandaX

Scintillation and Ionization Yield for Nuclear Recoils

- Dark matter detectors look for nuclear recoils (NR)
- Expected rate for dark matter interactions depends critically on the NR energy
- Scintillation and ionization yield for nuclear recoils are required to convert an observed NR signal to the deposited energy
- Therefore, any dark matter result from liquid noble gas detectors require knowledge of these parameters

Scintillation or S1

$$E = \frac{\mathrm{cS1}}{L_\mathrm{y}} \frac{1}{\mathcal{L}_\mathrm{eff}(E)} \frac{S_\mathrm{ee}}{S_\mathrm{nr}}.$$

Ionization or S2

$$E = \frac{\mathrm{cS2}}{Y} \frac{1}{\mathcal{Q}_\mathrm{y}(E)}.$$

- S1 - parameters that are intrinsic to the liquid are $L_{eff}(E)$, S_{ee} and S_{nr}
- S2 - $Q_y(E)$ is the charge yield

Liquid argon

Scintillation or S1

$$E = \frac{\mathrm{cS1}}{L_\mathrm{y}} \frac{1}{\mathcal{L}_\mathrm{eff}(E)} \frac{S_\mathrm{ee}}{S_\mathrm{nr}}.$$

Ionization or S2

$$E = \frac{\mathrm{cS2}}{Y} \frac{1}{\mathcal{Q}_\mathrm{y}(E)}.$$

- Two measurements of $L_{eff}(E)$ in the literature, but with large uncertainty, particularly for E < 25 keV
- No data exist in the presence of electric field (S_{ee}, S_{nr})
- No measurements exist of the ionization yield (Q_y)

Liquid xenon

Scintillation or S1

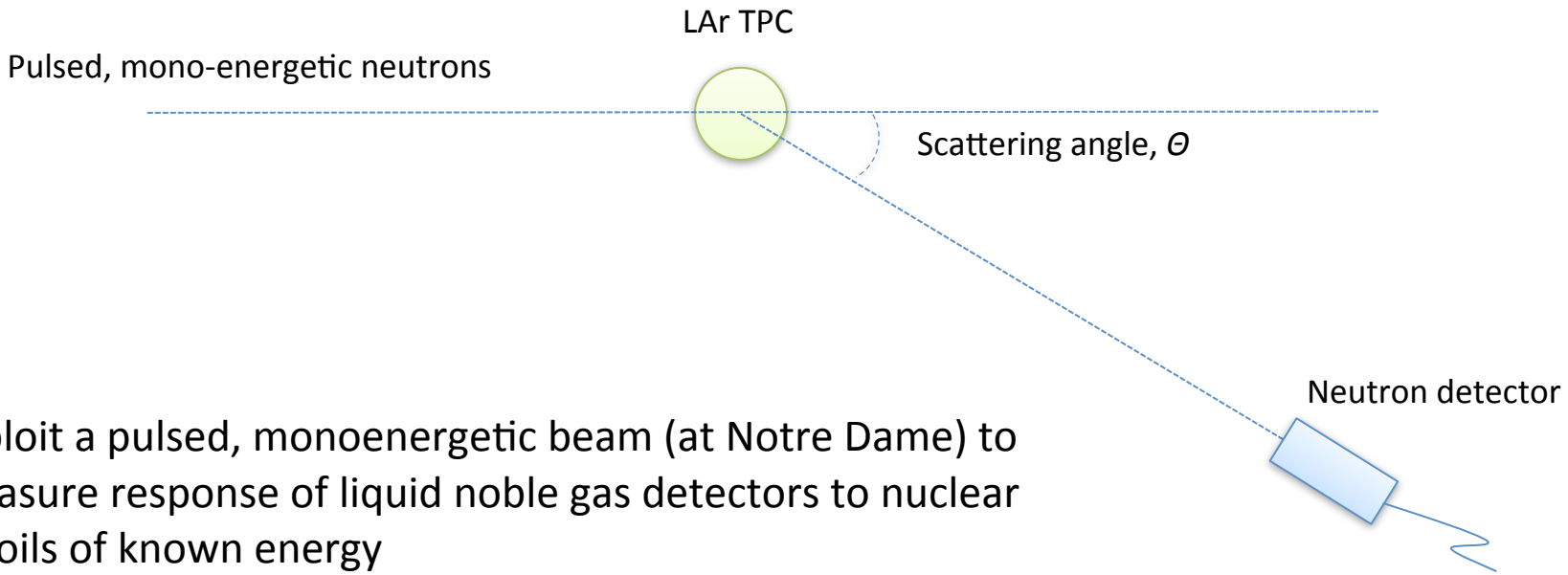
$$E = \frac{\mathrm{cS1}}{L_\mathrm{y}} \frac{1}{\mathcal{L}_\mathrm{eff}(E)} \frac{S_\mathrm{ee}}{S_\mathrm{nr}}.$$

Ionization or S2

$$E = \frac{\mathrm{cS2}}{Y} \frac{1}{\mathcal{Q}_\mathrm{y}(E)}.$$

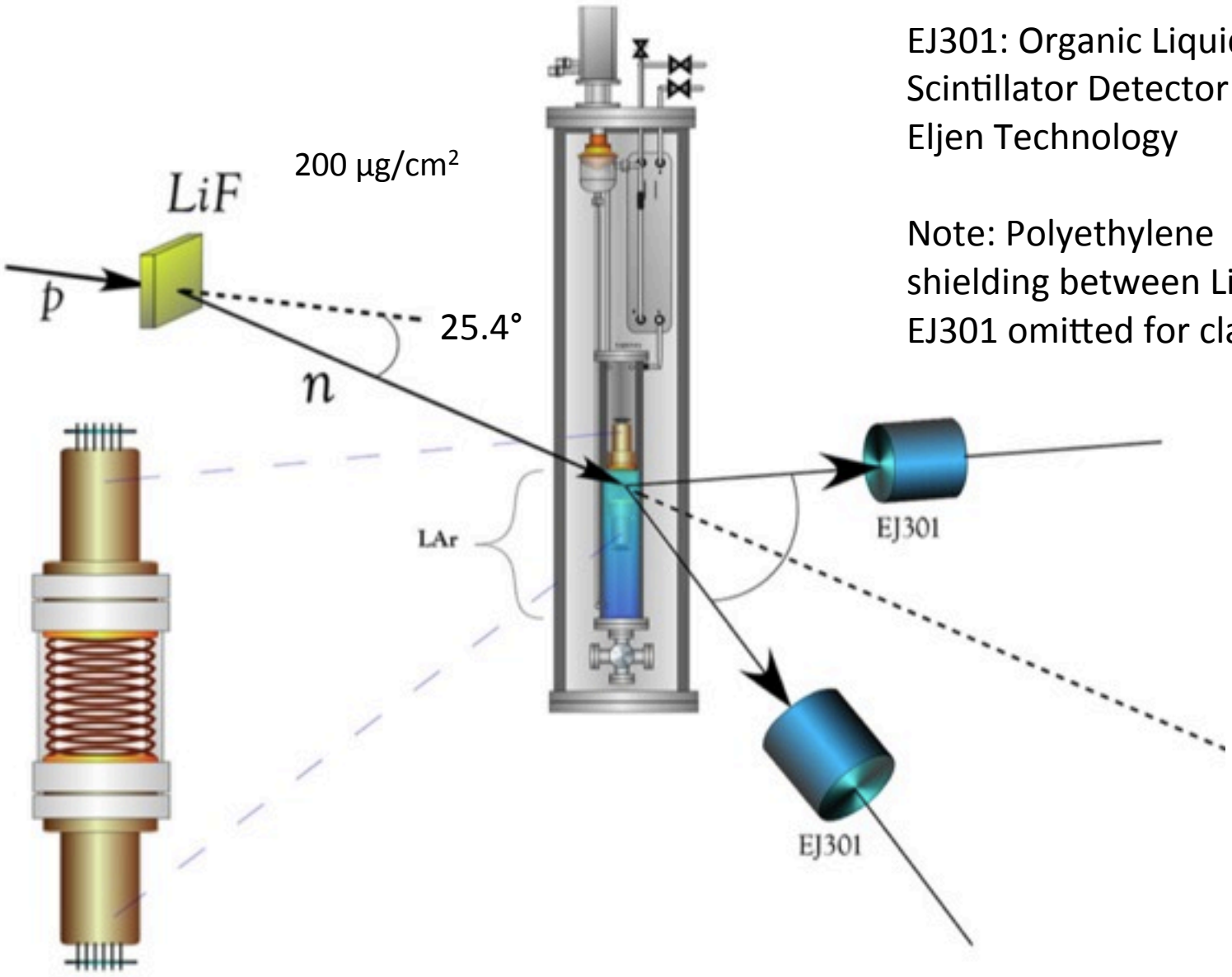
- Several measurements of $L_{eff}(E)$ in the literature, but relatively large errors, particularly at low energies (E < 6 keV)
  - Particularly relevant for light dark matter sensitivity, some controversy in the field (see e.g. 1106.0653, 1010.5187, 1006.2031, 1101.6080 from a few years ago)
- Very limited data exist in the presence of electric field (S_{ee}, S_{nr})
  - One measurement at high energy (56 keVr)
  - Several measurements with broad spectrum sources
- Ionization yield (Q_y) only measured with broad spectrum sources

The SCENE technique



- Exploit a pulsed, monoenergetic beam (at Notre Dame) to measure response of liquid noble gas detectors to nuclear recoils of known energy
- Tunable nuclear recoil energy by changing the neutron energy and the scattering angle
  - Neutrons of 500 keV - 1.5 MeV
  - Recoils of a few keV up to 50 keV
- Specially designed dual phase detector
  - Measure all parameters of interest
  - Minimize multiple scattering

The SCENE Experimental Layout

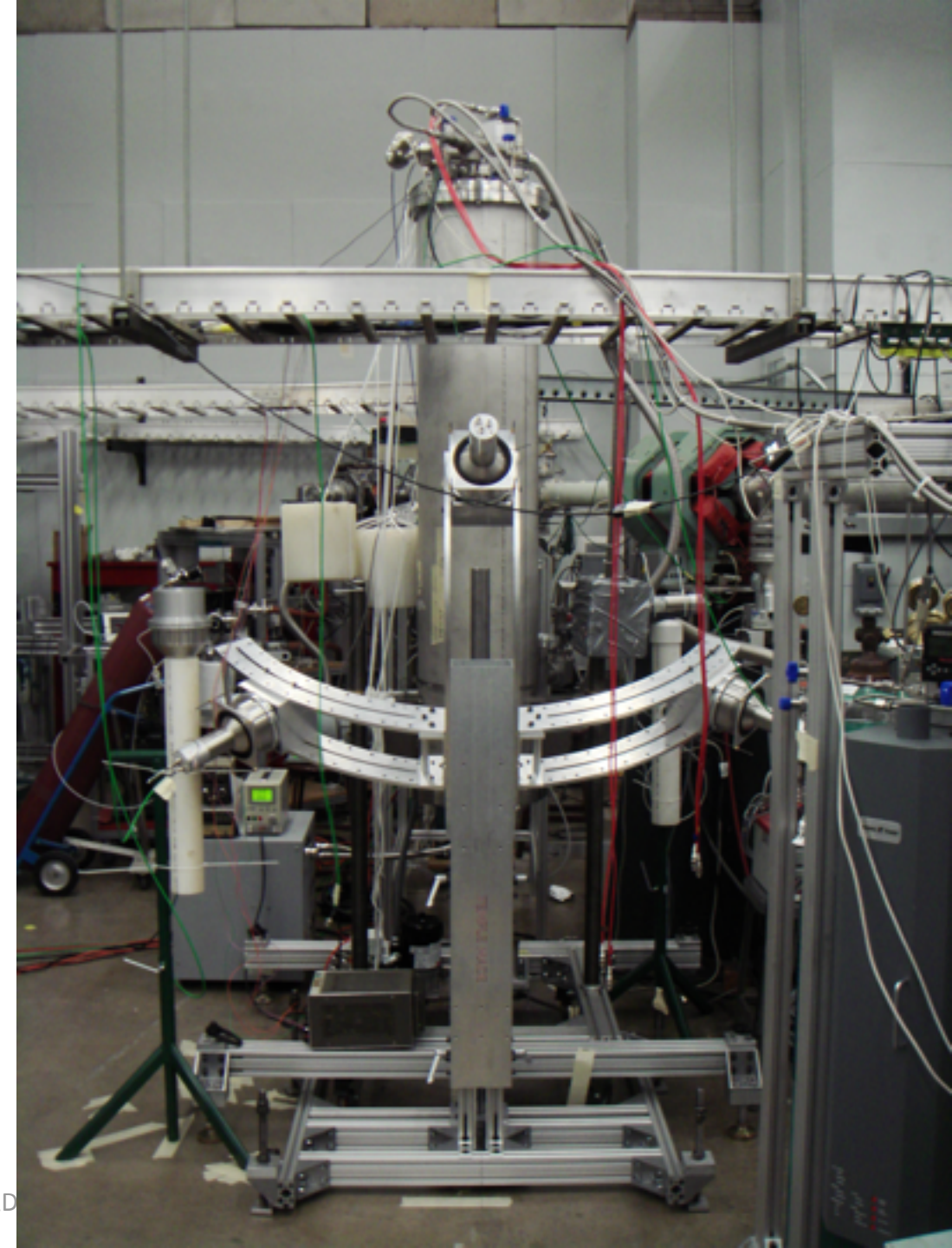


EJ301: Organic Liquid Scintillator Detector from Eljen Technology

Note: Polyethylene shielding between LiF and EJ301 omitted for clarity

The SCENE Collaboration

- Fermilab key contributor to detector design and construction
  - Gas handling system
  - Cryogenics - heat exchanger and condenser
  - Lifting fixture to allow easy installation in restricted space at Notre Dame
- True international collaboration, with significant contributions of manpower and hardware from Princeton, Temple, Naples, etc.



SCENE Progress

June 17 - July 2, 2013 - Two week beam run dedicated to scintillation/S1 measurements - First physics publication, Phys. Rev D **81**:045803 (2013)

Oct. 21 - Nov. 4 - Two week beam run dedicated to ionization/S2. Analysis is ongoing with paper expected by end of February

PHYSICAL REVIEW D, VOLUME 00,

Observation of the dependence on drift field of scintillation from nuclear recoils in liquid argon

T. Alexander,[1,2] H. O. Back,[3] H. Cao,[3] A. G. Cocco,[4] F. DeJongh,[2] G. Fiorillo,[4] C. Galbiati,[3] L. Grandi,[5,3] C. Kendziora,[2] W. H. Lippincott,[2] B. Loer,[2] C. Love,[6] L. Manenti,[7] C. J. Martoff,[6] Y. Meng,[8] D. Montanari,[2] P. Mosteiro,[3] D. Olvitt,[6] S. Pordes,[2] H. Qian,[3] B. Rossi,[4,3] R. Saldanha,[3,9] W. Tan,[10] J. Tatarowicz,[6] S. Walker,[6] H. Wang,[8] A. W. Watson,[6] S. Westerdale,[3] and J. Yoo[2]

(SCENE Collaboration)

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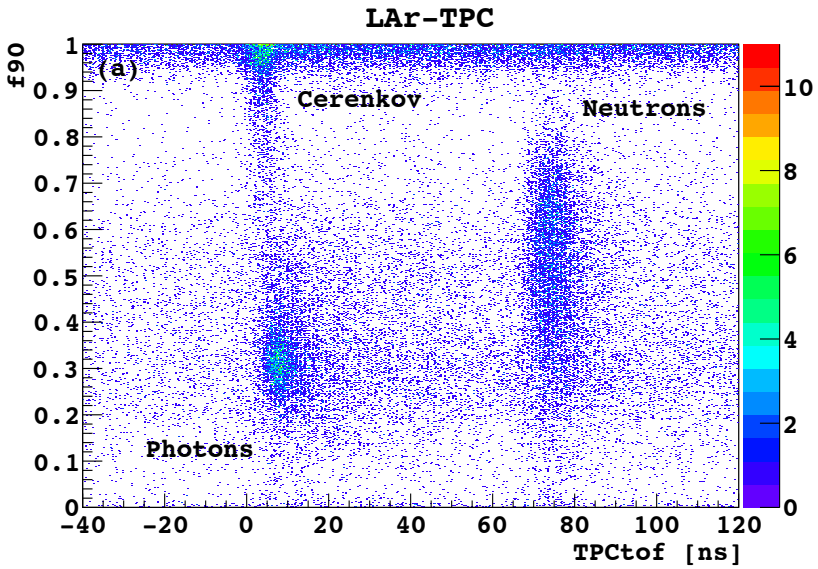
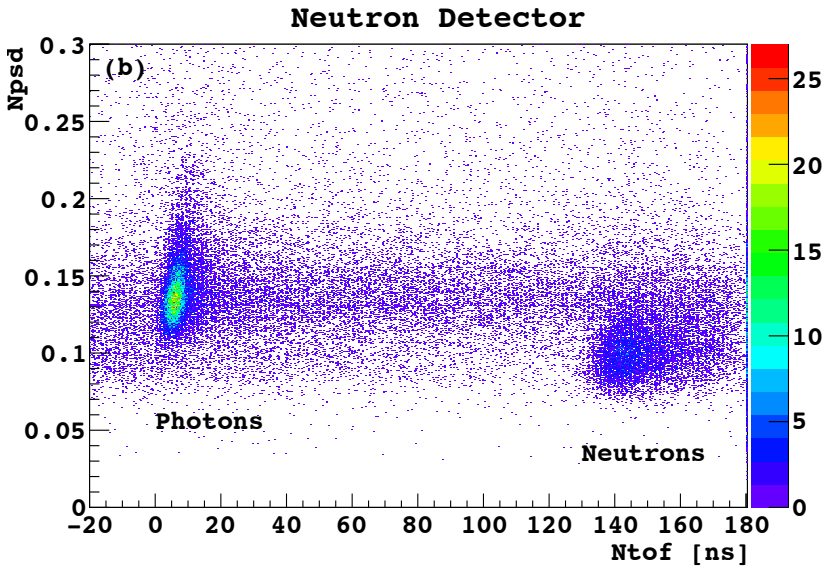
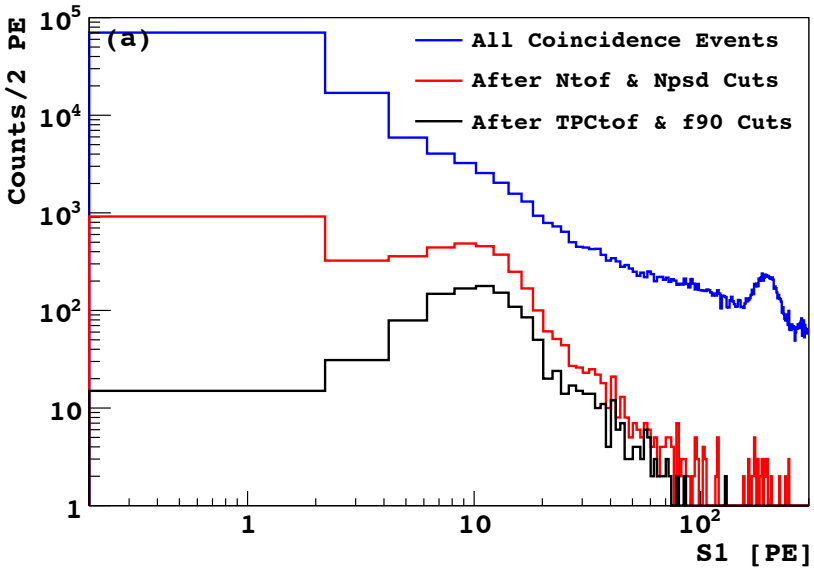
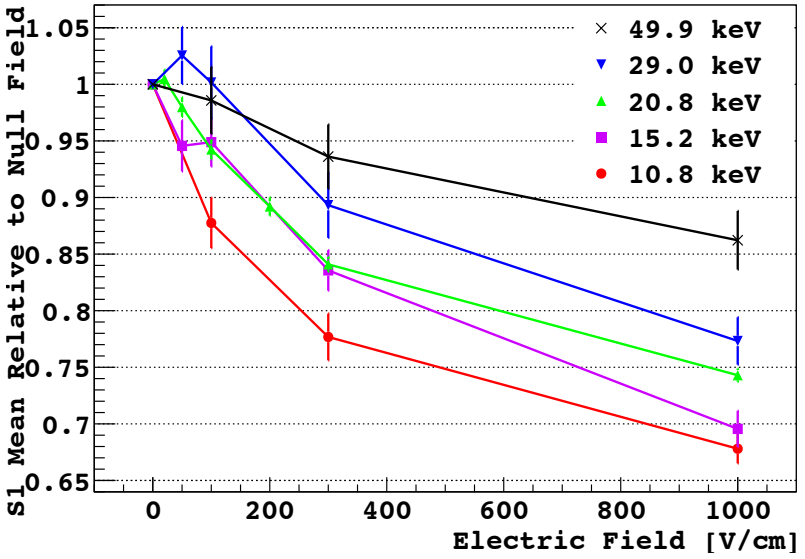
(Received 25 June 2013; revised manuscript received 8 September 2013)

SCENE - Pulse Shape Discriminant vs. Time of Flight

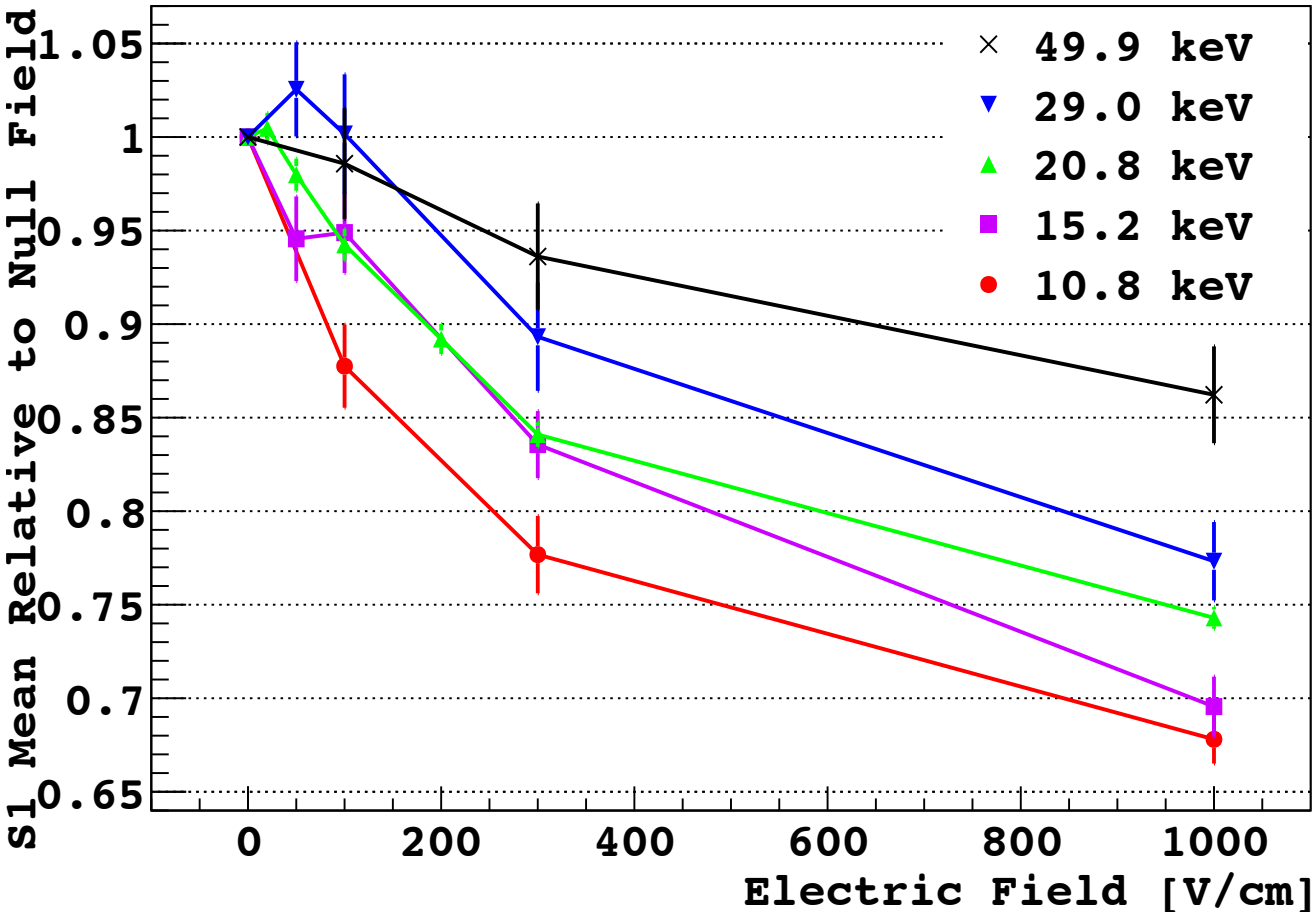






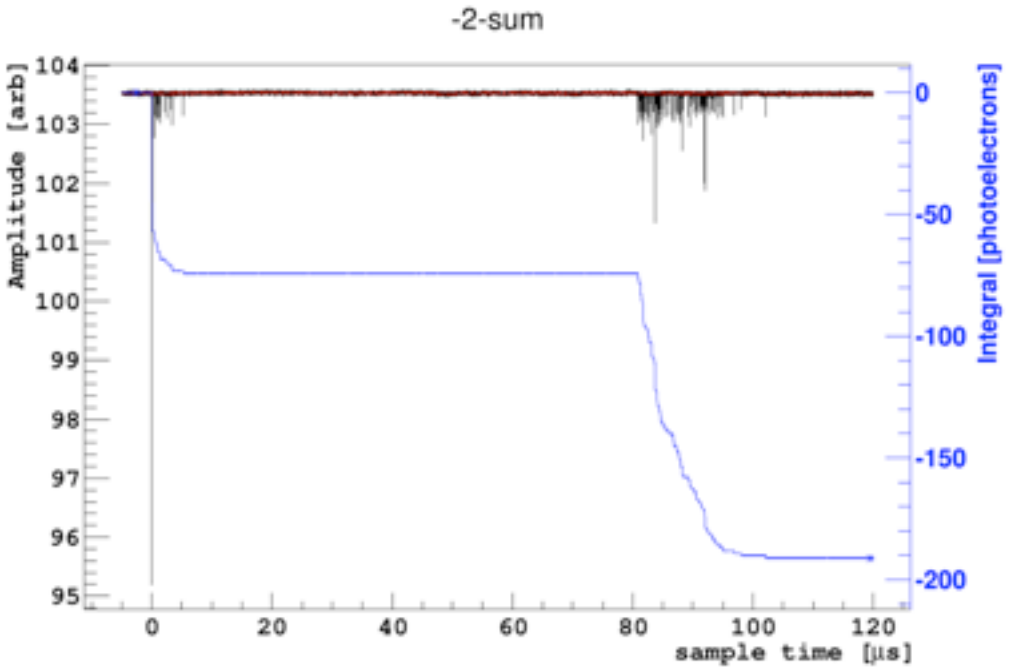


SCENE Results



- Key result - less light at lower energy in presence of an electric field - **unexpected outcome that affects operation of dual phase argon dark matter searches**

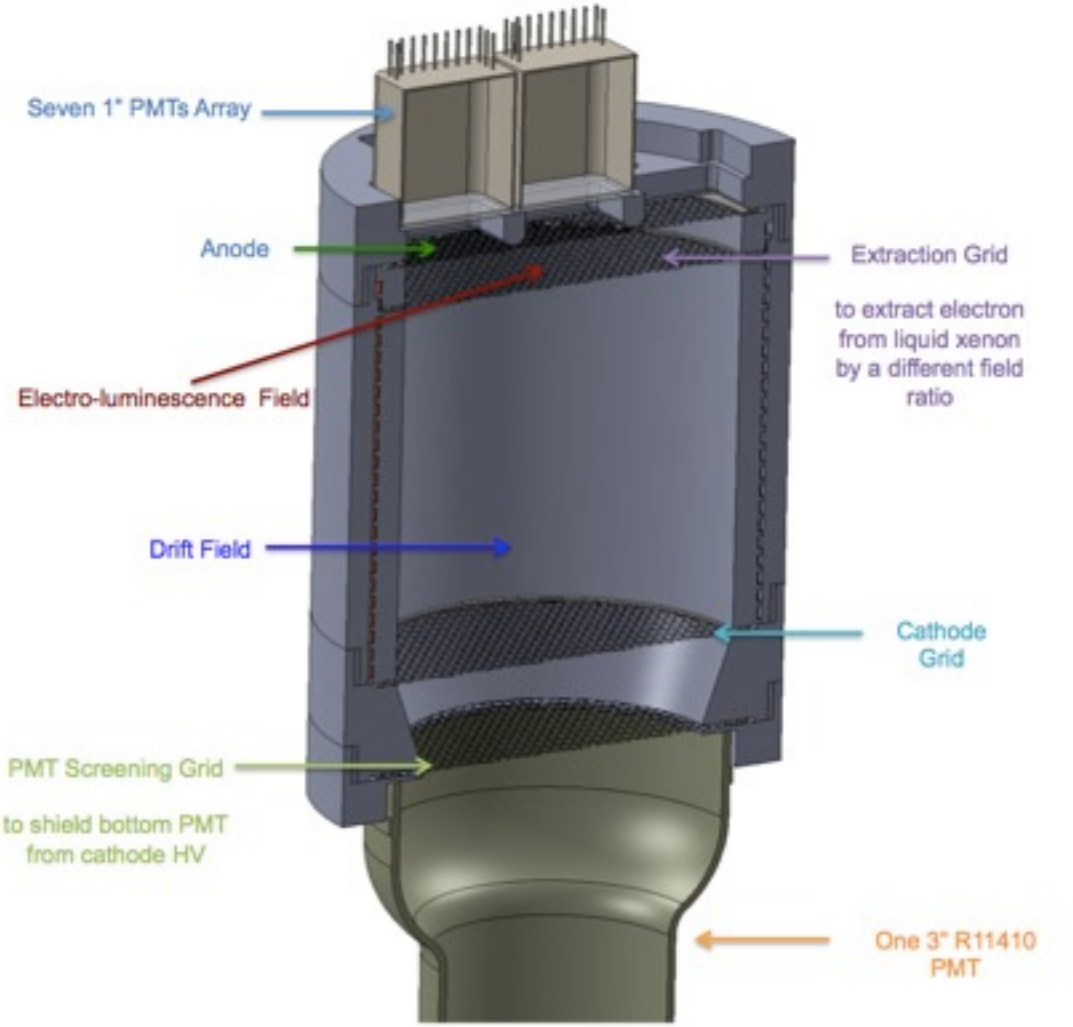
SCENE - Still to come from existing data



- A complete $L_{eff}(E)$ analysis, already in demand by other LAr experiments
- Analysis of ionization channel, including first measurement of charge yield for low energy nuclear recoils in LAr

Plans for Xenon run

- Liquid Xe run scheduled for March-April with new TPC under construction at UCLA
  - Direct test of the model used by liquid xenon dark matter experiments (NEST)
  - Will therefore confirm/ invalidate dark matter limits set by these experiments
  - Very high impact
- Fermilab again to contribute structural support to enable use of detector at Notre Dame



Y. Meng 2013, UCLA

After Notre Dame runs

- Other noble gases are impractical in current setup (He and Ne being primary gases of interest)
- SCENE apparatus is still useful as a generic test stand for LAr/LXe
  - E.g. influence of impurities on S1/S2 signals

After Notre Dame runs

- For example, FNAL scientists already in a new effort with Profs. Juan Collar and Paolo Privitera of the University of Chicago, exploiting SCENE infrastructure to test Xenon response
  - Detector now running, two months after first idea

SCENE is generic R&D

- Measured properties of these noble gases are important to all liquid noble gas dark matter searches and the field of dark matter as a whole
  - DarkSide, DEAP, MiniCLEAN, ArDM, LUX/LZ, Xenon100/1T, PandaX, XMass, any future combination
- Other experiments interested in the response of these liquids
  - Neutrino-nucleus coherent scattering (CENNS), etc.

Resources

- Several Fermilab scientists are involved in SCENE scientific effort, particularly analysis, paper preparation, DAQ (Yann Guardincerri, Hugh Lippincott, Ben Loer, Stephen Pordes)
- Completion of Xenon apparatus will require <1 week of technician time to build lifting fixture
- Xenon run will probably require technician help for setup at Notre Dame (1 person, 1-2 days)
- Follow up runs, if they occur, will have similar requirements
- Generic studies (such as current xenon effort with UChicago) also use ~1 week of technician labor per run

1) Briefly summarize the current state of the program, discussing what has been learned and what are the remaining issues.

- Argon scintillation data set complete and published
  - Argon scintillation is strongly affected by an electric field for low energy nuclear recoil events
  - Has had a direct influence on operation of Darkside-50 and will affect other LAr TPCs
- Second S2 data set collected in fall 2013

2) What is the proposed scope of the R&D program for the next two years, and what resources are required for that program?

- Second paper in progress
  - Argon ionization data under analysis
  - Final Argon L_{eff}
- Xenon run scheduled for Mid-March
- Possible followup run later this year depending on results
- Scene apparatus is a generic test bed for liquid noble gas scintillation studies

3) Compare the program with similar programs worldwide. Are we doing leading work in this area?

- Only current experiment using this technique
- No comparable measurements in LAr
- Xenon experiments will benefit by independent verification of their results
- Clearly relevant for the entire field

4) Which parts of the program should be considered generic R&D and which parts should be considered project specific?

- Scene is generic R&D, of interest to all noble liquid dark matter experiments
- Also of interest for any noble gas seeking to observe nuclear recoils (e.g. coherent scattering)

5) Will this research likely result in new projects at the lab?

- No new projects of similar or larger scope
- Possible use on small scale (generic use of apparatus)